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A Study of Cryptogamic Crusts at
Comanche Canyon and Largo Mesa New Mexico

Juanita Ladyman and Esteban Muldavin

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Juanita Ladyman
and
Esteban Muldavin

New Mexico Natural Heritage Program
University of New Mexico
Albuquerque, NM

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A Study of the Cryptogamic Crust at Comanche Canyon and Largo Mesa, New Mexico.

Summary.

This study was designed to describe the relationship between terrestrial cryptogam and vascular plant cover in a juniper-pinon pine community in New Mexico. The specific hypotheses that were examined were as follows: a) Tree spacing influences the presence of cryptogamic crust. b) Crusts are absent under the pinon/juniper canopy. c) Crusts are absent in open clearings. d) There is a negative association between the presence of grass and cryptogamic crusts. Two different sites were measured and compared. The primary site was Comanche Canyon in north central New Mexico. A second site, Largo Mesa in west central New Mexico, was chosen for comparison and corroboration of findings on the primary site.

At Comanche Canyon soil samples were taken from areas with and without cryptogamic crusts to explore the possibility that the differential pH value between the soil surface and the soil at 9-12 cm depth could be used to determine the degree of leaching (infiltration) that had occurred.

The conclusions reached in this study were: Short distances (<4 m) between trees prevent the development of crusts rich in lichens and algae. The extent to which woody and needle debris, and the pinon or juniper canopy covers an area, is inversely correlated with the amount of cryptogamic crust on the area. At both mesas, the presence of pebbles was significantly positively associated with the adjacent ground being colonized by terricolous cryptogams. Largo Mesa, an area with significantly higher grass cover than the mesa at Comanche Canyon had a significantly lower cover of cryptogams. Conversely, forbs were positively correlated with certain components of the cryptogamic crust. The two latter points should be interpreted while considering that species of both vascular plants and cryptogams differed between the two sites and that there were edaphic and environmental differences. Also at both mesas on transect lines between lengths 8-12 m the spaces opened up by the falling of a tree have a significantly lower cover of cryptogams, without a different degree grass cover, than similar spaces without the prior influence of a tree canopy. The absence of crust in open clearings may be either an affect of the residual influence of canopies of trees that have since fallen. Alternatively, it may be due to the cryptogams being unable to tolerate an exposed environment or, yet a third possibility is that cryptogams are not compatible with vascular plant species that favor such environments.

The results from this preliminary study on the cryptogamic crust and its influence on differential soil pH (as a measure of infiltration) suggested that the presence or absence of the crust influenced the differential pH of the soil. In addition the differences in differential pH between crust and bare ground were related to the composition of the crust. Therefore, this method could lead to insights on the how the different types of crusts influence erosion processes.

The measure of percent cover on a transect was successful in providing estimates of the amount of cover as influenced by tree spacing, canopy cover, and debris. However, the frequency data was very valuable in determining the distribution of higher plant species. As this study has shown that, generally, cryptogamic crusts are considerably reduced on thick needle debris further studies that investigate transects that exclude the canopy from calculation but are expanded to widths of one m between trees should be considered so that a greater area is evaluated for both cryptogams as well as vascular plants. For example, this approach could allow spatial analysis of the association between cryptogams and grass tussocks. A survey on areas that had been recently harvested for fuel wood would be a useful comparison to these two undisturbed areas. Further studies on a greater number of locations along with examination of tree spacing within the individual locations should be undertaken so that generalizations can be made from the specific conclusions reached in this particular study.

The abundance of microphytic (cryptogamic) soil crust is believed to be an important indicator of the extent to which an area has been disturbed and may provide insight on the progress in the recovery of a logged, grazed or otherwise disturbed community. Ocular estimates are subject to operator variability and probably underestimate the biomass of crust present. They are also very time consuming. Developing a simple procedure based on the measurement of chlorophyll on the soil surface (0-3 cm) after Beymer and Klopatek (1992) may ultimately be an accurate and rapid method to determine the condition of the soil surface for purposes of monitoring land deterioration and/or soil erosion.

Introduction.

The detrimental effects of grazing (Abatorov, 1990; Brotherson et al., 1983; Nash 1992) and foot traffic (Cole, 1990) on cryptogamic and microphytic soil crusts have gained attention especially in the last ten years (West, 1990). Less documented is the effect of fuel wood harvesting, or logging, activity on cryptogamic crust formation. In addition to mechanical damage done to the soil surface, tree spacing, canopy cover, and debris cover would alter dramatically after wood harvesting activity.

This study is a preliminary survey made at sites having a relatively undisturbed condition (absence of recent grazing and woodcutting) to obtain an estimate of the influence of tree spacing on cryptogamic crust abundance and compare two pinon-juniper communities for the presence and abundance of terrestrial cryptogams along with their association with grasses and forbs. In the time available, estimates of cover were made visually, without the aid of a microscope, therefore the cryptogamic crust was recorded rather than the microphytic soil crust (West, 1990).

Loope and Gifford (1972) reported that sites with cryptogamic crust had higher infiltration of water than chained (no lichen cover) areas. It was hypothesized that if greater infiltration occurred through cryptogamic soils the difference between soil surface pH and the pH at depths of 9-12 cm would be more negative than that for bare soil areas i.e., if the pH immediately under the soil surface was less than the pH at a depth of 9-12 cm leaching or infiltration would have occurred. Therefore a more negative differential pH of cryptogam crusted soil compared to "bare soil" would indicate greater infiltration. If the surface soil had a higher pH than the deeper soil then there may be surface accumulation of calcareous material or possibly acidifying microbial activity at the lower depth which would complicate any interpretations. A preliminary test of this hypothesis was made.

Site description.

Comanche Canyon is being proposed as a Research Natural Area by the National Forest Service. Largo Mesa is currently under consideration for RNA designation (Dunmire and Toll, 1987). Both sites support pinon-juniper woodland with no history of recent fuel wood harvesting or cattle grazing activity. Although the sites differ in proportions of *Pinus edulis* to *Juniperus monosperma* and in the extent of grass cover both belong to the *Pinus edulis/Bouteloua gracilis* (PIED/BOGR) habitat type described in the USDA Forest and Woodland habitat types classification for northern New Mexico and northern Arizona (USFS, 1987).

The site at Comanche Canyon is on a mesa approximately 0.05 km wide x 0.39 km long (Figure 1). The elevation ranged from 2329.3 m at the south western end to 2358.8 m at the north eastern end. On the mesa the soils are very fine and classified as Eutroboralfs, sandy-mixed residuum. Average annual rainfall ranges from 32.3 to 55.6 cm and the snowfall from 35.6 to 101.6 cm depending upon the year. The July average temperature is 22.2 °C The January average temperature at is -2 °C

The Largo Mesa site is about 0.62 km x 1.27 km and elevation ranged from 2432.9 m to 2439 m (Figure 2). The soils on Largo Mesa are mainly thin Cerrillos soils over a zone high in lime. Average annual rainfall is 40.6 cm and average annual snowfall is 78.7 cm. The July average temperature is 20 °C. The January average temperature is -1.1 °C.

Because of the lack of disturbance both sites provided an excellent opportunity to study cryptogamic crusts of communities with predominately pinon-juniper overstorey.

Methods.

Sample plots. Surveys were carried out in July and August, 1992. Sample plots were determined as follows: A live tree was picked at random. This was denoted as the "central tree" of the sample plot. North, south, east, and west compass bearings were determined and the area divided into quadrants. In each quadrant a line, unobstructed by canopy cover of adjacent trees, was taken to another live tree which was most often the nearest tree to the central tree in the quadrant. This unit of 4 lines was termed a plot.

The length of the line between the central tree and the second tree was measured, and the cover on the transect was recorded to the nearest millimeter. The tape measure, graduated in mm, was placed at ground level for the measurements. The spatial position of cryptogamic crust, vascular plant species, litter, dead trees and bare ground on the line was recorded. Vascular plants and the dominant cryptogams were sampled for future, positive species identification. Estimates of cover were made visually, without the aid of a microscope. Basal and canopy area of grasses (summed together), and canopy area of forbs and shrubs were measured. In this report forbs include *Yucca baccata*. Litter was classified as either a) woody debris (obvious twigs, pine cones etc) or b) needles debris (needles and fine debris). The degree of decomposition of trees on the line was also noted. In addition, vascular plants within 0.5 m of the line was noted as a means of judging species diversity in the area. The height and canopy cover over the line of the tree at the end of the respective lines was measured. The lichens were classified in the field according to their morphological (foliose, crustose, fruticose) characteristics. Where even this gross delineation could not be made they were classed as lichen. There was also a black crust of unknown composition that most likely included more than one species including cyanobacteria and other unicellular algae. This crust was very distinctive and recorded in a separate category (BUC). It may be of similar composition to that referred to by Nash et al. (1977) in their studies of desert cryptogams in the southwestern United States.

In Comanche Canyon there were 16 plots. The line lengths were placed into four classes, 0-3.99 m long (SSH); 4-7.99 m long (MSH); 8-11.99 m long (MLG); and greater than 12 m long (LLG). In each class there were 16 lines. The 16 plots covered the mesa at Comanche Canyon very effectively and their distribution is shown on the map in Figure 1. At Largo Mesa 4 such plots were surveyed, the positions of which are described in Figure 2. The area to the far west was apparently considerably drier than the rest of the mesa and no plots were examined in that region. At Largo Mesa lines between 8-11.99 m long were investigated and thus only compared to lines of the same class size (MLG) at Comanche Canyon.

For both sites, the slope of any individual line was usually negligible (<1%) and at most 4%.

Plant species identification. Species of vascular plants and the predominant lichens were identified. Cryptogam species are listed in Appendix 1. Appendices 2 and 3 list the species of vascular plants found at the plots on the mesa at Largo Mesa and Comanche Canyon respectively.

Soil pH measurement. At Comanche Canyon paired soil samples were taken at 0-3 cm and 9-12 cm below the soil surface in 5 different areas where there was an absence and presence of cryptogamic crust within three feet. The samples were taken as much as possible from areas of homogenous crust formations. Three to 5 replicates were taken from each site. The cryptogamic crust and the hardened organic crust (neither greater than 0.75 cm) were removed respectively from the soil surface. Two sites were analyzed for the effect of BUC crust on the differential pH. Three sites were analyzed for the effect of a moss crust, two for a fruticose lichen crust which was predominately of a *Cladonia* species, and one site was analyzed on which the cover was a mix of mosses and lichens. Soil samples were analyzed using a pH meter (Piccolo ATC pHmeter, Hanna, Woonsocket, USA) within 24 hours after collection. Soil was mixed thoroughly with approx 30 ml water and left for 1.5 hours during which time it was frequently agitated. The soil/water slurry was filtered through filter paper (Whatmans #4) and the pH of the filtrate recorded.

Figure 1. Site plot plan at Comanche Canyon. Plot numbers reflect the order in which the plots were surveyed.

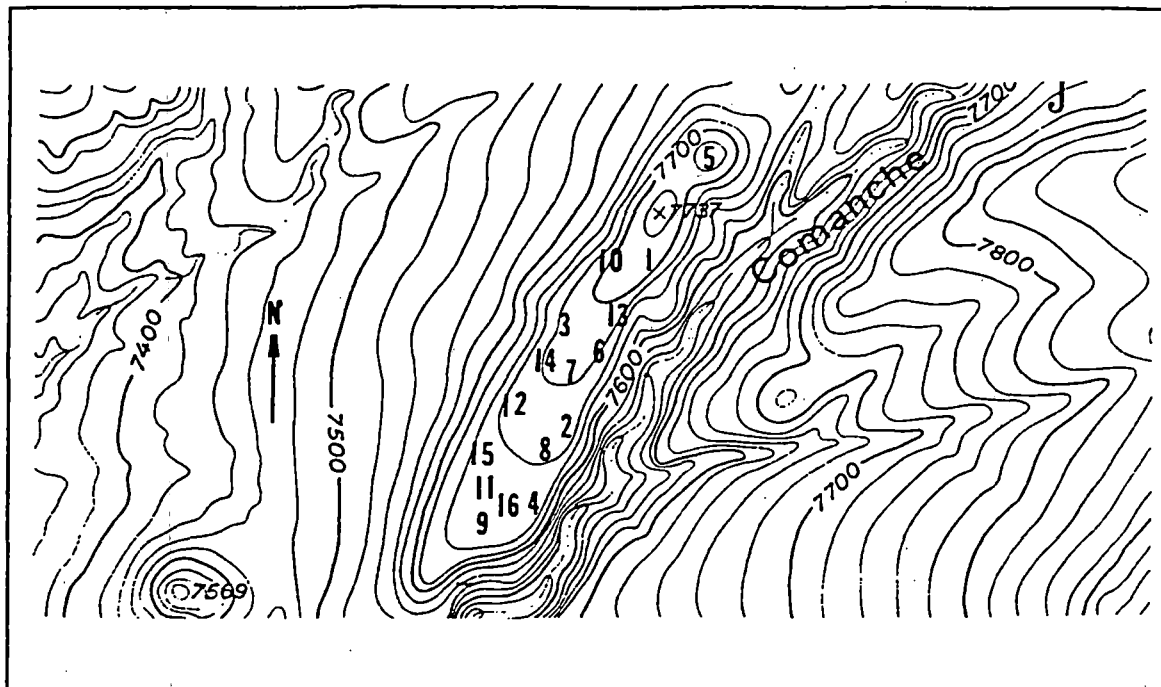
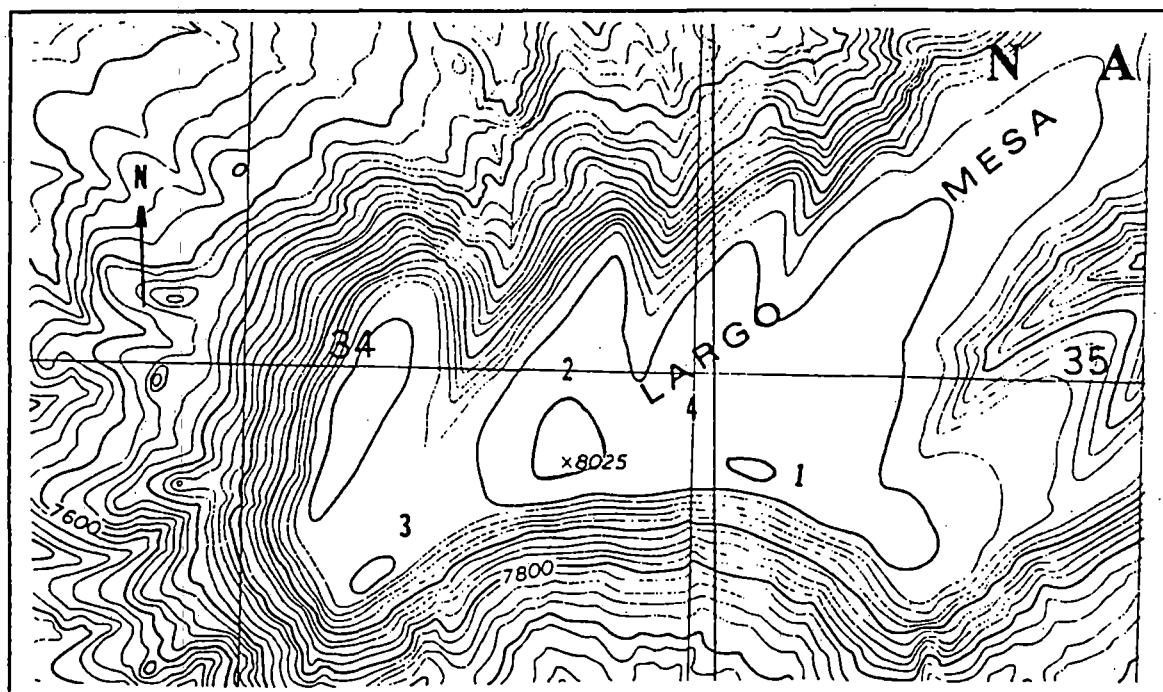


Figure 2. Location of plots on Largo Mesa.



Analysis of the results. The question of whether tree density affects the percentage-cover of microphytic crust was considered by placing the transect lines of different lengths into like classes and testing the variation in percentage-cover among the classes by analysis of variance (ANOVA) after arc-sine transformation of the data. Arc-sine transformation of the data was performed because it is likely that such percentage data has a binomial, rather than a normal, distribution. The cover between trees of a similar length apart (8-11.99 m; classes MLG) were compared between Comanche Canyon (CC) and Largo Mesa (LM). The choice of the MLG class for comparison was made on the visual estimation that this was the most common tree spacing at LM.

If there were no significant differences in the vascular plant distribution or the cover on the transects between the plots on LM the experimental design would permit considering the influence of aspect on crust abundance. Using nested ANOVA the amount of cryptogamic cover that was on the line in the 1 m that extended immediately past the canopy in each quadrant was compared.

The effect of the presence of a dead tree on the line was also considered using multivariate analysis of variance at both Largo Mesa and Comanche Canyon. Correlation analysis was performed to determine the association between abundance of cryptogams with abundance of forbs, grasses, needle debris, woody debris and pebble cover. Correlation analysis was made on a per line basis, rather than a per class basis, in order to take advantage of the exact line length data collected.

Paired t-tests at the different sites and then ANOVA to include all sites was used to analyze the pH data.

Results

Comanche Canyon.

Vascular plant distribution.

The observation that pinon (*Pinus edulis*) trees far out numbered the junipers (*Juniperus monosperma*) in this stand was reflected in the species frequency among trees chosen to end transects. Of the 128 trees included in the study only 3 were junipers. Representative areas on the whole mesa were examined. Even though the distance between trees, on average, tended to increase from the northern to the southern part of the mesa, lengths of the lines examined were not biased toward any particular area. Variability in the vascular plant species around the mesa may be attributed to edaphic and/or climatic differences. For example, *Artemisia tridentata* was present only around the most southern plot, plot 9 (position 16 on the 3-dimensional graphs in the Figures 3a and 3b), and *Cercocarpus montanus*, only in plot 7 which was mid mesa. There was a trend for the number of forb species, and the frequency with which individual species occurred within 1 m of the transect lines, to increase from the northern to southern end of the mesa (Figure 3a).

Using "percent of the transect covered" by a vascular plant species may lead to misinterpreting the distribution of species. Rather frequency was chosen to describe the distribution of species. For example, in Figure 4 the percent transect cover of *Yucca baccata* is compared to the frequency of *Yucca baccata* associated with the transect ± 1 m. The trend, according to "percent cover", is that yucca is absent from the northern end of the Mesa and substantially increases in the southern plots (Figure 4a). The high percentage cover of line 11 is due to one of those lines being short and containing a very large yucca plant. However, plants were found offline in other plots making the frequency of plants found offline in the plot areas more accurately a reflection of the general distribution (Figure 4b). This type of situation is typical where small plots and relatively large and widely spaced plants are considered (Kershaw, 1973). Considering both ways of recording yucca abundance there is a substantial increase in yucca from north to south across the mesa but simple presence and absence relationships for yucca and cryptogamic crusts cannot be established. This result underlines the importance of considering areas larger than a single, 2 cm-wide line when investigating the relationships between vascular plant species and cryptogams.

Opuntia species were to be found all over the mesa but were more prevalent in the southern area and were also in greater abundance on the longest transects (Figure 5 and Table 1).

Ipomopsis multiflora was only on the longest transects. This distribution was likely to be a result of the greater amount of light available on the longest lines. *Bahia dissecta* and *Lesquerella rectipes* were both very numerous on Comanche Canyon mesa. The frequency of their distribution is described in Figure 6. In general, the pattern of their distribution was similar. There were no significant differences among line lengths for the percent cover by forbs (Figure 7 and Table 1).

The longest lines had a statistically significant higher number of species of forbs and grasses (see Table 2; Asterisks denote homogenous groups as determined by the Scheffe range test at the 95% confidence level.). This could be due to the fact that light requiring, as well as shade tolerant, plants are both more likely to be represented on the long lines. Seedling trees (<1' tall) were in evidence on the mesa (Figure 8a) indicating new tree establishment may be occurring.

Although there was an apparent trend towards less percent grass cover in the northern part of the mesa (Figure 3 b) there were no significant differences in the percentage grass cover among plots. Neither was there any difference in grass cover, on a percentage basis, between the classes of line lengths (Figure 7a). *Aristida* was only on MLG and LLG. The other grass species were found, to a greater or lesser extent, on at least some lines in each class.

Figure 3. a) Distribution of the number of species of grasses and forbs per plot. The z axis describes the plot position in a west to east direction across the mesa and the y axis describes the plot position in the north (1) to south (16) direction.

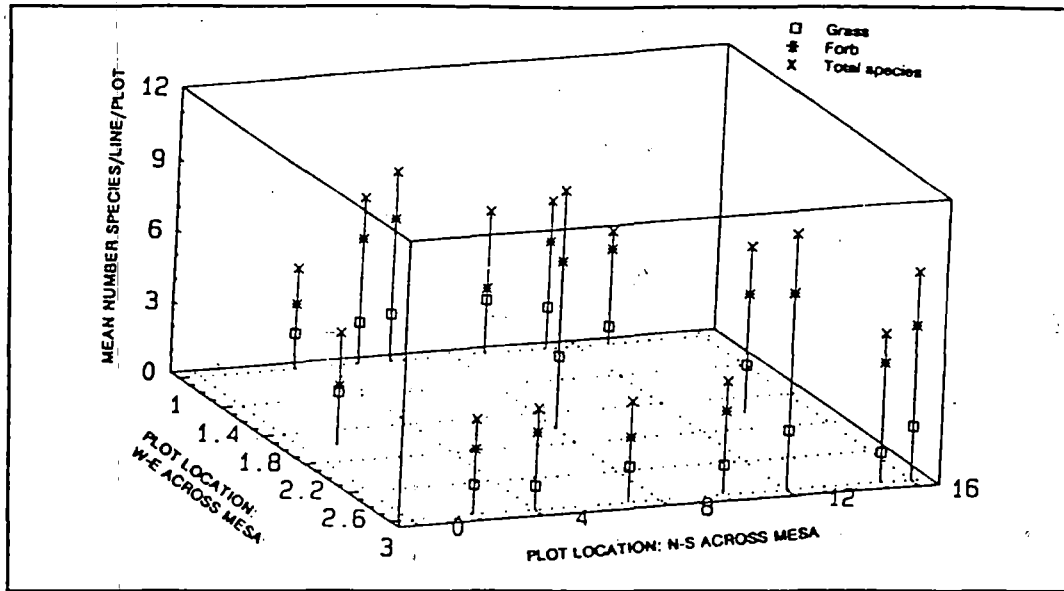


Figure 3. b) Distribution of the percent cover by grasses and forbs on the mesa at Comanche Canyon. The x axis describes the plot position in a west to east direction across the mesa and the y axis describes the plot position in the north (1) to south (16) direction.

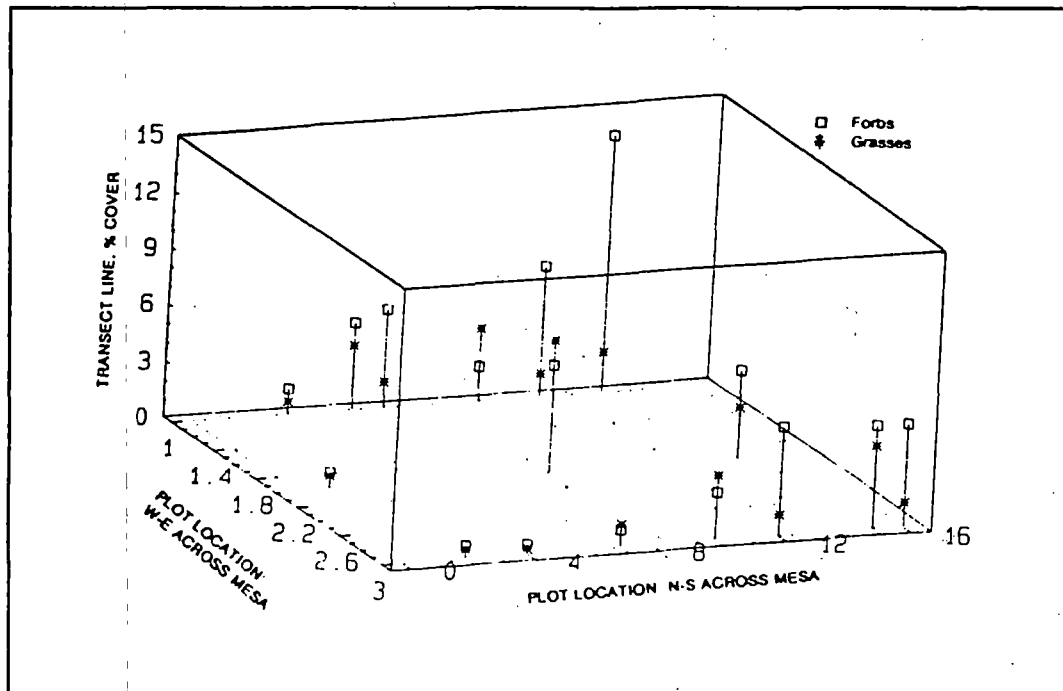


Figure 4. a) The distribution of *Yucca baccata* as described by the number of individual plants occurring within 1 m of the transect line.

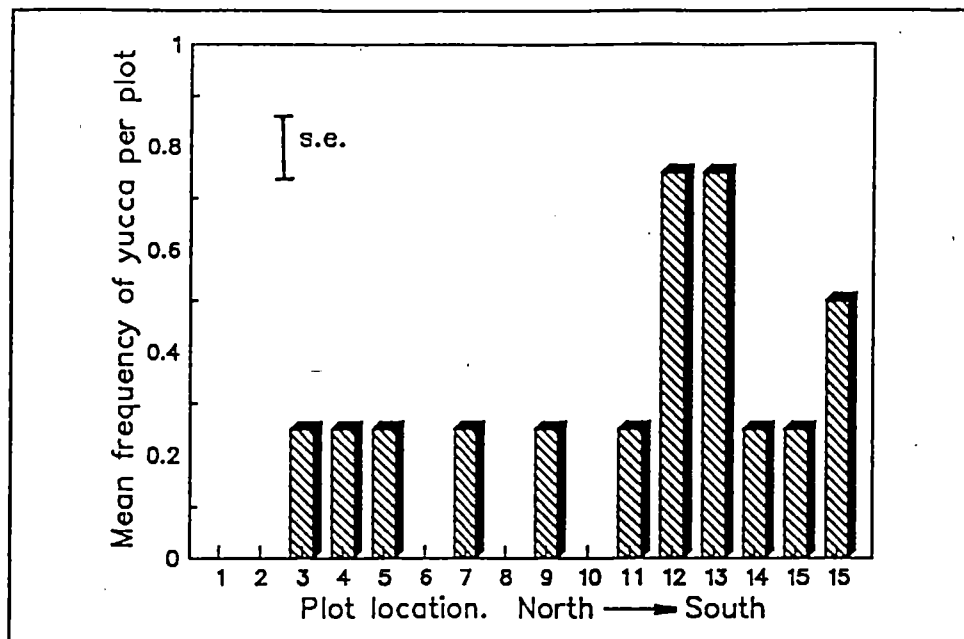


Figure 4. b) Mean percent (%) cover of line occupied by *Yucca baccata*.

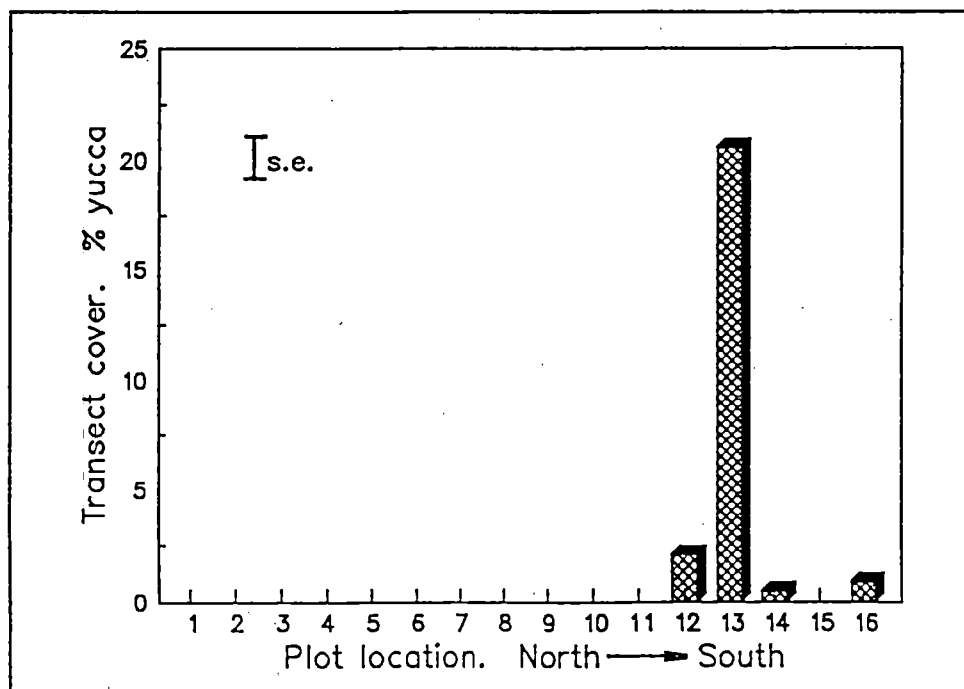


Figure 5. Distribution of *Opuntia* species along the mesa in a north to south direction. Insert graph shows that the percent cover of *Opuntia* increased on the longest lines (LLG class. SSH; lines 0-3.99 m, MSH; lines 4-7.99 m, MLG; lines 8-11.99 m, LLG; lines >12 m).

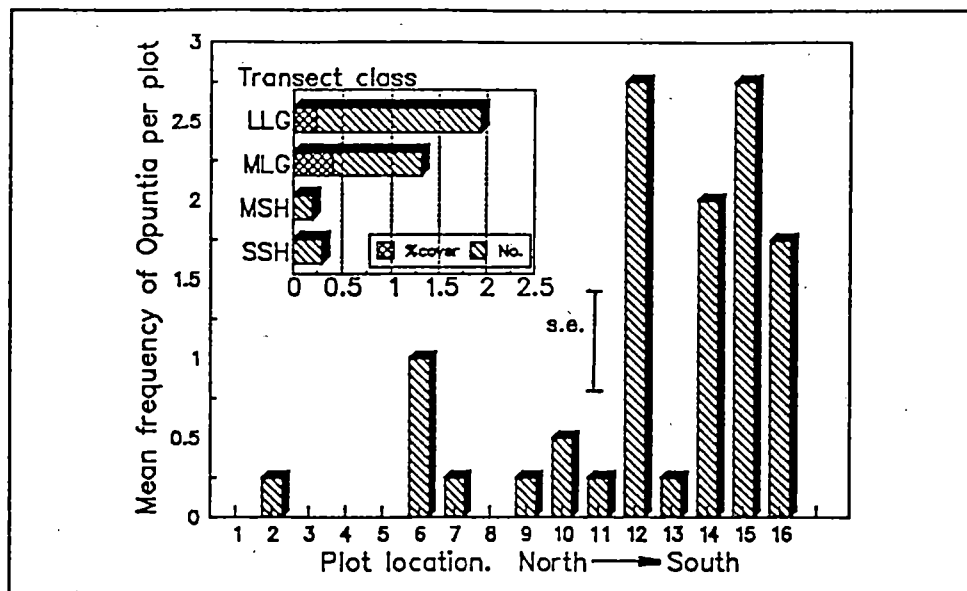


Figure 6. Distribution of *Bahia dissecta* and *Lesquerella rectipes* at Comanche Canyon.

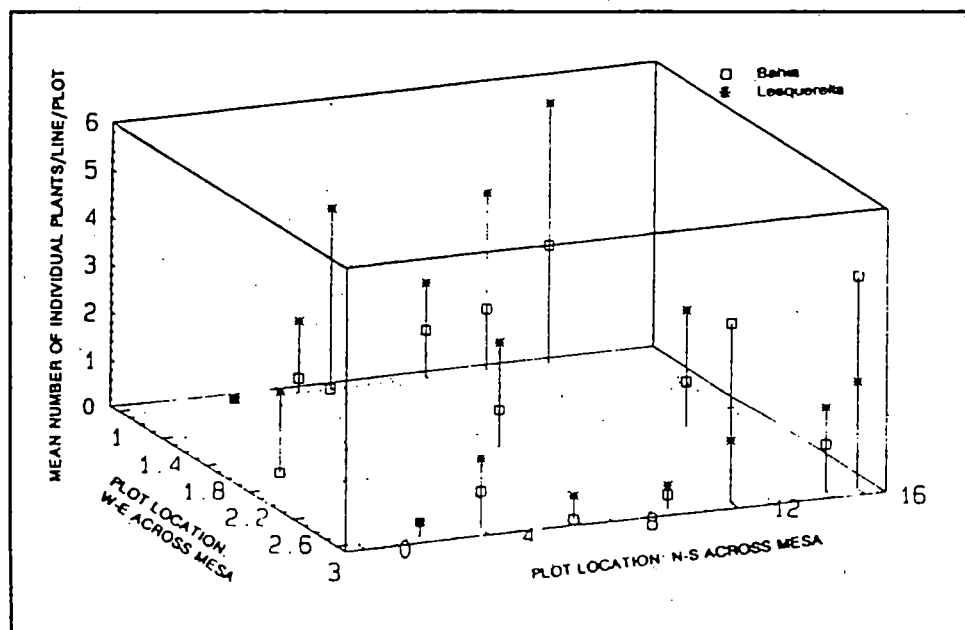


Figure 7. a). Graph describing the mean percent cover by vascular plants on transect lines of different lengths between trees at Comanche Canyon.

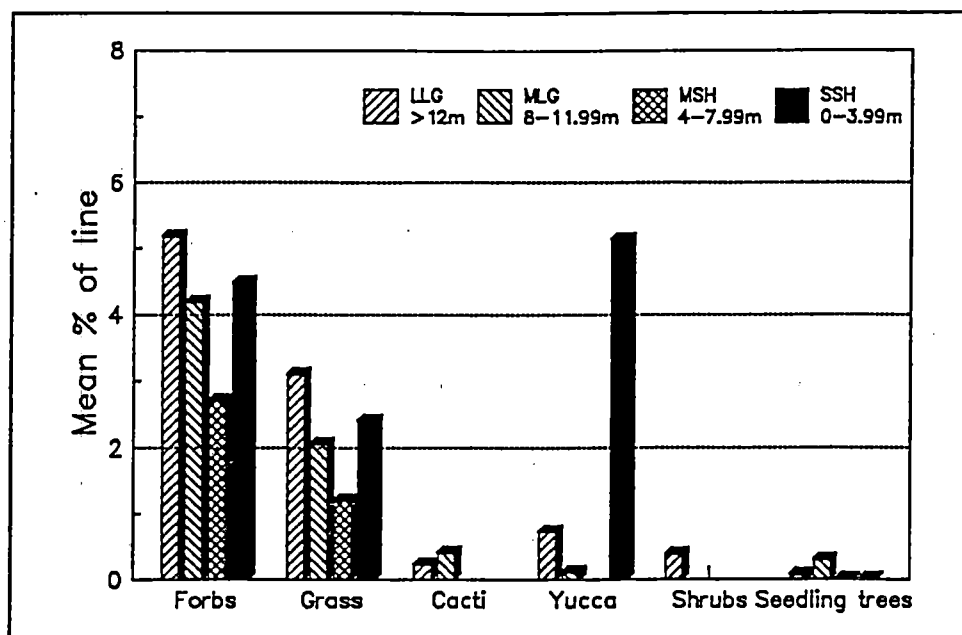


Figure 7. b). Graph describing the mean percent cover by cryptogams on transect lines of different lengths between trees at Comanche Canyon.

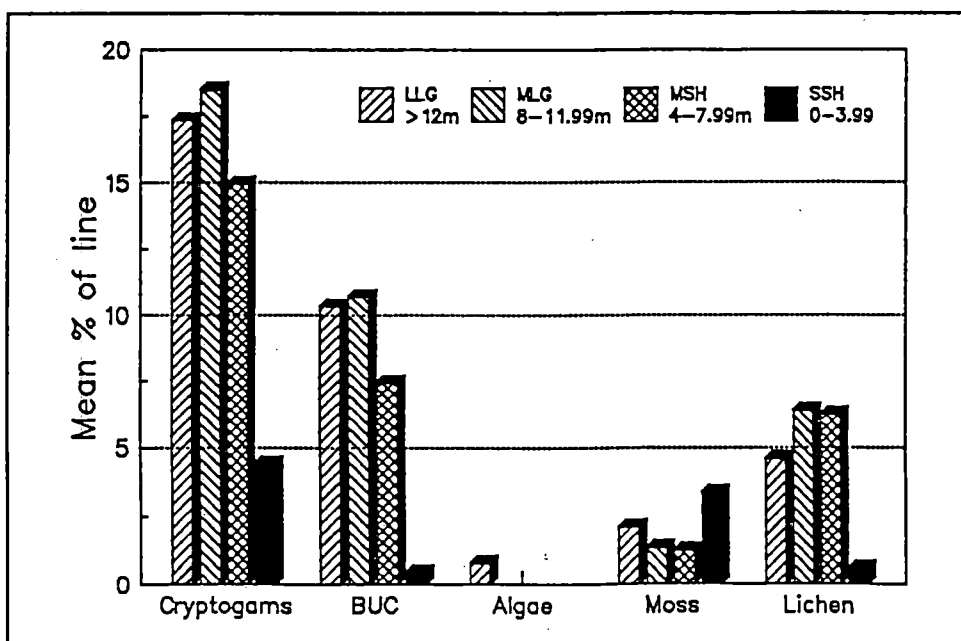


Table 1. Means of percent cover on the different classes of transect lines (16 lines per class) at Comanche Canyon.

Parameter measured	Class ¹				Probability ²
	LLG	MLG	MSH	SSH	
Mean length of line (cm)	1478	988	609	272	***
		Mean % of line			
Total microphytic crust	17.36	18.5	14.97	4.44	**
BUC	10.64	10.74	7.47	0.46	***
Algae	0.79	0.00	0.00	0.00	ns
Moss	2.12	1.35	1.25	3.38	ns
Lichen	4.6	6.41	6.25	0.6	*
Saxicolous lichen	0.34	0.21	1.00	0.13	ns
Epiphytic lichen	0.15	0.16	0.19	0.2	ns
Canopy	32.49	38.66	57.82	90.25	***
Woody debris	7.43	8.67	7.85	11.56	ns
Needle debris	38.00	51.2	71.0	95.9	***
Forbs	5.19	4.19	2.71	4.48	ns
Grass	3.10	2.07	1.22	2.41	ns
Cacti	0.24	0.41	0.00	0.00	*
Yucca	0.74	0.12	0.00	5.14	ns
Seedling trees	0.08	0.31	0.02	0.02	ns
Shrubs	0.39	0.00	0.00	0.00	ns
Rock	1.74	2.86	3.06	0.13	ns
Pebbles	0.79	0.73	0.72	0.00	ns

¹ SSH; lines 0-3.99 m, MSH; lines 4-7.99 m, MLG; lines 8-11.99 m, LLG; lines >12 m.

² ns. Not significantly different $P > 0.05$;

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$

Table 2. Mean number of species per transect account according to transect length at Comanche Canyon.

Class	Number ¹ grasses species	Number forbs species	Number grasses and forbs species
LLG ²	2.6 *	7.4 *	10 *
MLG	1.8 * *	4.3 *	6.1 *
MSH	1.4 *	4.0 *	5.5 *
SSH	1.2 *	2.5 *	3.7 *

¹ The asterisk denotes homogenous groups at the 95% confidence level using the Scheffe range test.

² SSH; lines 0-3.99 m, MSH; lines 4-7.99 m, MLG; lines 8-11.99 m, LLG; lines >12 m.

Cryptogam cover.

Although in Figure 8 the data suggest that there may be a greater amount of cryptogamic crust in the north part of the mesa there were no significant associations between plot location and total cryptogam cover. This trend of higher cryptogam cover and lower grass cover (compare Figure 8 to Figure 3b) is also suggested by the results of correlation analysis on a per line basis where there was a negative, but statistically insignificant, correlation between percent grass cover and cover by total cryptogamic crust.

There were significant differences in the percent cryptogamic crust between the line length classes (Figure 7b and Table 1). The SSH class (0-3.99 m) had the lowest percentage cover by total cryptogams but the highest moss cover. *Nostoc (communis)* was observed only on 2 lines and those in the LLG class. This may imply that the filamentous blue-green favors unshaded sites with little debris (Table 1). As would be expected the canopy covered a much higher percentage (90%) of the line in the SSH class than the other classes (Table 1). A lower percentage of moss, lichen and BUC occurred under the canopy than would be expected if cryptogams were distributed equally along the line, implying that the cryptogams favor areas outside the dense canopy (Table 3). The highest cover was on MLG and LLG lines (Table 1). Lichen cover was much reduced in the SSH class and tended to decline at the longer lengths in the LLG class. It may be inferred from this that the predominant species of cryptogam at Comanche Canyon favor moderately shady and moist areas with only moderate debris. As a percentage of the total lichen crustose lichen was essentially absent on SSH lines (Table 4). In general, crustose lichen are known to favor drier sites.

There was a significant negative correlation between total cryptogam cover and the extent to which both the canopy and debris covered the line (Table 5). The negative correlation between needle debris and canopy cover applied only to the lichen and BUC components of the crust (Table 5). However, it was noted while surveying, that the foliose and fruticose lichens apparently could tolerate some intimate and dense cover by needles under the tree canopies.

Irrespective of position on the mesa, as the debris increased on the line, the total cryptogamic crust decreased (Figure 9a). However, when the components of the crust were considered it was clear that BUC was reduced as needle debris increased, but moss did not show such a trend (Figure 9b and Table 5). Considering each line individually (regardless of line class) there was a significant negative correlation between the BUC and lichen components of the crust, and the extent to which the canopy and debris covered the line (Table 5).

The composition of lichen with respect to morphological type was similar among the other classes of transect although trends may be seen (i.e. an increase in crustose and fruticose lichen and a decrease in foliose lichens as the lines increase in length). *Peltigera canina* was the major foliose species at Comanche canyon. Other lichen identified at Comanche Canyon are listed in Appendix 1.

Pebbles were measured individually on the lines. SSH lines were almost devoid of pebbles and needle debris dominated the lines in this class. There was a positive correlation between the presence of pebbles and lichen and BUC crusts but not with moss (Table 6). This is not including saxicolous lichen which were found on the rocks and pebbles to the same extent on all lines (Table 2).

However, pebbles (>2 cm diameter) were frequently just off the line but would have had influence on the microclimate of soil on the line. Hence, a pebble class system was adopted to determine if it would better describe the "pebble content" of the area immediately adjacent to the line. Lines with no pebbly soil (rocks and stones were excluded from consideration) were classed soil class 0, with <5% pebbly soil class 1, with <10% class 2, with <20% class 3, etc. Considering the individual lines the shortest line class (SSH) was 0.00, and MSH, MLG and LLG were 1.31, 2.13, 5.00 respectively. Even though the classes appear to differ from the %cover by pebbles, on a per line basis there was a positive correlation between class and individual pebbles on the line. The significant correlation between % cover by (individual) pebbles and cryptogamic crust matched that found between pebble-soil class and cryptogamic crust (Figure 10). One explanation for the tendency for loose pebbly soil to promote crust colonization is that the microtopography

would promote small water ways, and also influence dew and frost formation because of significant microclimate modification. The number of pebbles found to cover the transect lines tended to decline from north to south of the mesa (Figure 10).

Lichen that favored a wood substrate for growth were found on woody debris. They were a species of *Usnea*, and from the amount found on the lines they were also equally distributed among the line classes (Table 1).

On a total of 14 transects in classes MLG and LLG, trees had died and branches or parts of the trunk lay on the transects. The trees were in various states of decomposition but all had lost leaves and most small branches with the larger branches present but frequently broken. The amount of woody material left to decompose was estimated in most cases to be upwards of 60% of the original material. There was no influence of the presence of a dead tree on grass cover on any of the lines (Figure 11). The degree of total cryptogamic cover was markedly reduced on the MLG lines with a dead tree on the line (Figure 11). However there was no statistically significant difference when the lines of longer lengths were taken into consideration (Figure 11). This phenomenon may have been due to a combination of factors that are exhibited by a difference in environment between the two class lengths of line. For example, longer lines have greater light availability and are possibly drier even though the amount of woody debris could be the same. In addition, assuming that the dead trees are a similar size when alive the presence of a live tree on a shorter line would provide a greater amount of canopy cover on a shorter line than a longer line. Therefore an explanation for the difference in the result when different line length classes are considered could reflect the residual affect of canopy on the slow growing cryptogamic crust.

Figure 8. Mean BUC, moss, lichen, and total cryptogamic crust cover per plot in relation to the position of the plot on the mesa.

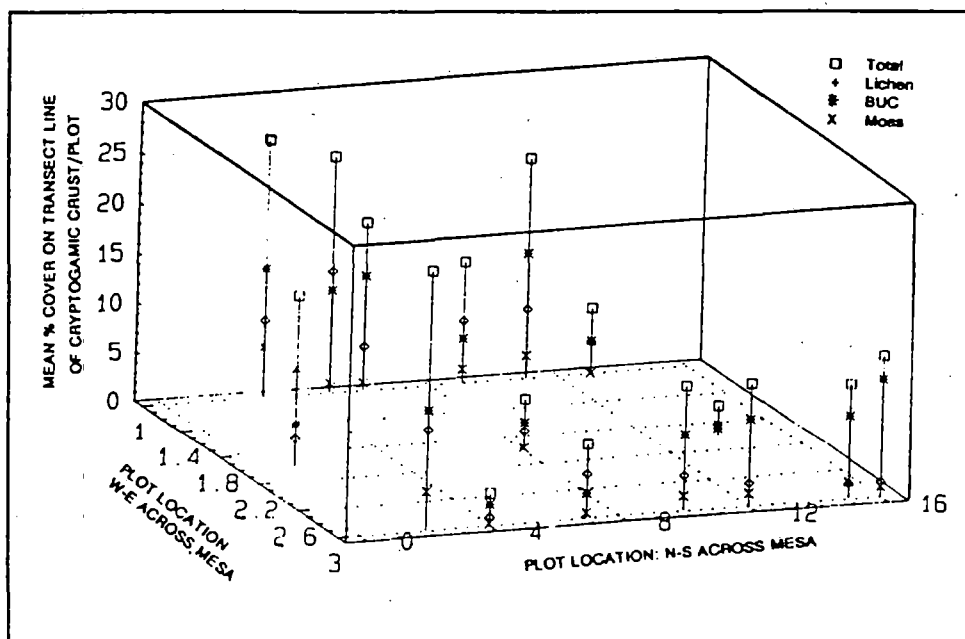


Table 3. Proportion of cryptogamic and debris cover on the line that was under the canopy.

Form Canopy (% of line)	LLG ¹ 32.49	MLG 38.66	MSH 57.82	SSH 90.25	Probability ² ***
% of line under canopy					
Lichen	5.50	7.41	35.45	12.87	*
Moss	19.39	20.21	34.88	25.00	ns
BUC	2.17	2.92	22.4	6.39	ns
Needle debris	81.61	74.11	76.49	92.53	**
Woody debris	44.52	52.42	54.49	91.56	***

¹ SSH; lines 0-3.99 m, MSH; lines 4-7.99 m, MLG; lines 8-11.99 m, LLG; lines >12 m.

² ns. Not significantly different $P > 0.05$;

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 4. The composition by morphological type of the terricolous lichen.

Form	LLG ¹	MLG % of total lichen	MSH	SSH ²	Probability ³
Foliose	10.17	13.32	28.83	9.60	*
Fruticose	64.05	54.05	37.73	52.67	ns
Crustose	9.75	9.73	5.08	0.00	ns
Unidentified ⁴	16.03	22.90	28.36	37.76	--

¹ SSH; lines 0-3.99 m, MSH; lines 4-7.99 m, MLG; lines 8-11.99 m, LLG; lines >12 m.

² Only 3 lines in SSH class included lichen. On one 100% lichen was fruticose; on one 100% lichen was unidentified and on the third 58% was fruticose and 29% foliose.

³ ns. Not significantly different $P > 0.05$;

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$

⁴ Lichen that was not readily distinguishable between the forms was included in the total lichen value (Table 1 and 3). This unidentified lichen was usually associated with BUC.

Table 5. Correlation coefficients demonstrating a significant negative correlation between needle debris and lichen and BUC cover.

	Correlation coefficient	P
Needle debris:		
and BUC	- 0.60	0.000
and lichen	- 0.40	0.006
and Moss	+ 0.02	ns

Figure 9. Plot showing a) the relationship between total cryptogamic crust with debris cover and position on the mesa; b) relationship between moss and BUC with debris cover and position on the mesa.

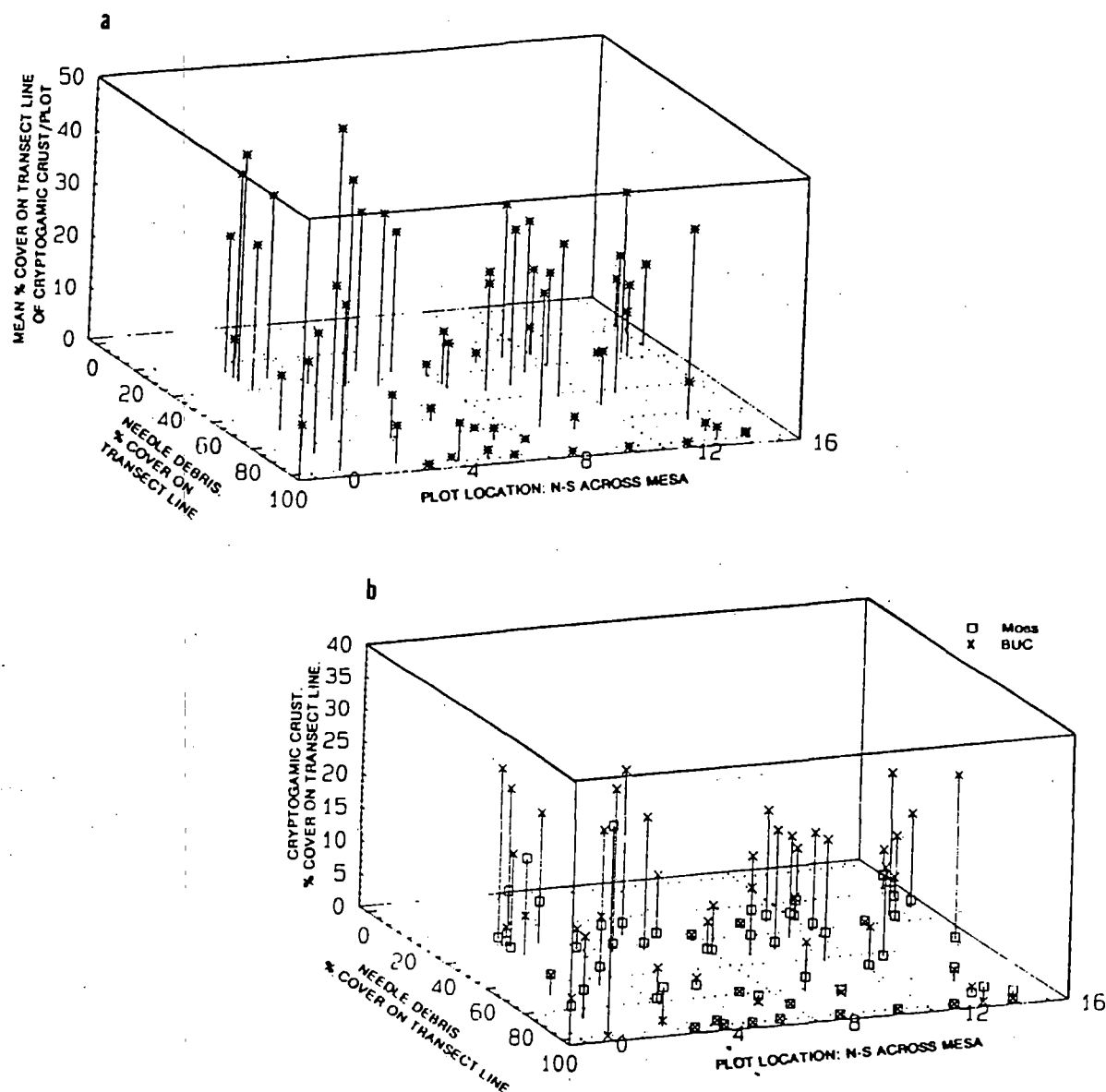


Table 6. The correlation between pebbles and lichen and BUC.

	Correlation coefficient	Probability
Pebbles and:		
total crust	0.4	0.001
lichen crust	0.3	0.006
BUC crust	0.4	0.004
moss crust	0.06	0.645

Figure 10. A graph showing the relationship between mean percent cover by cryptogamic crust and the 'mean percent cover by pebbles on a line' with the lines position on the mesa.

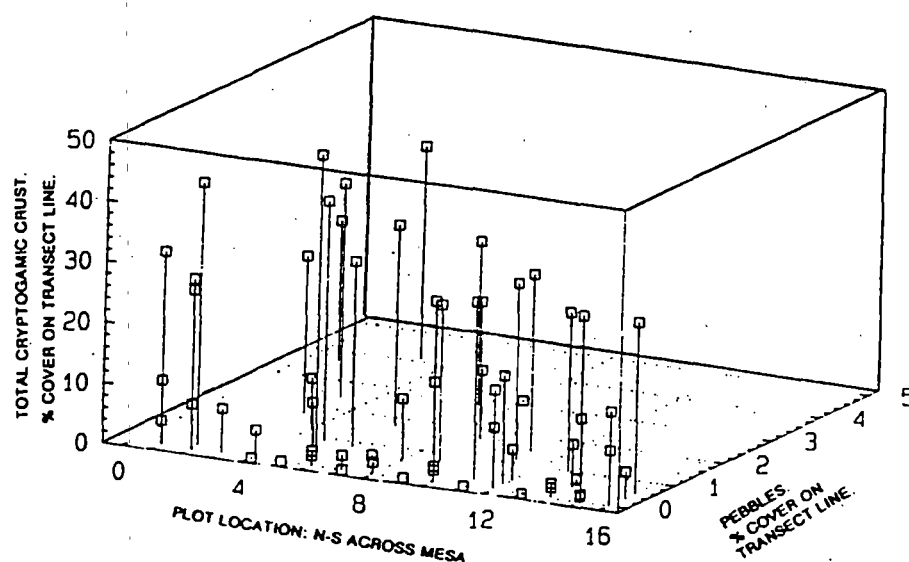
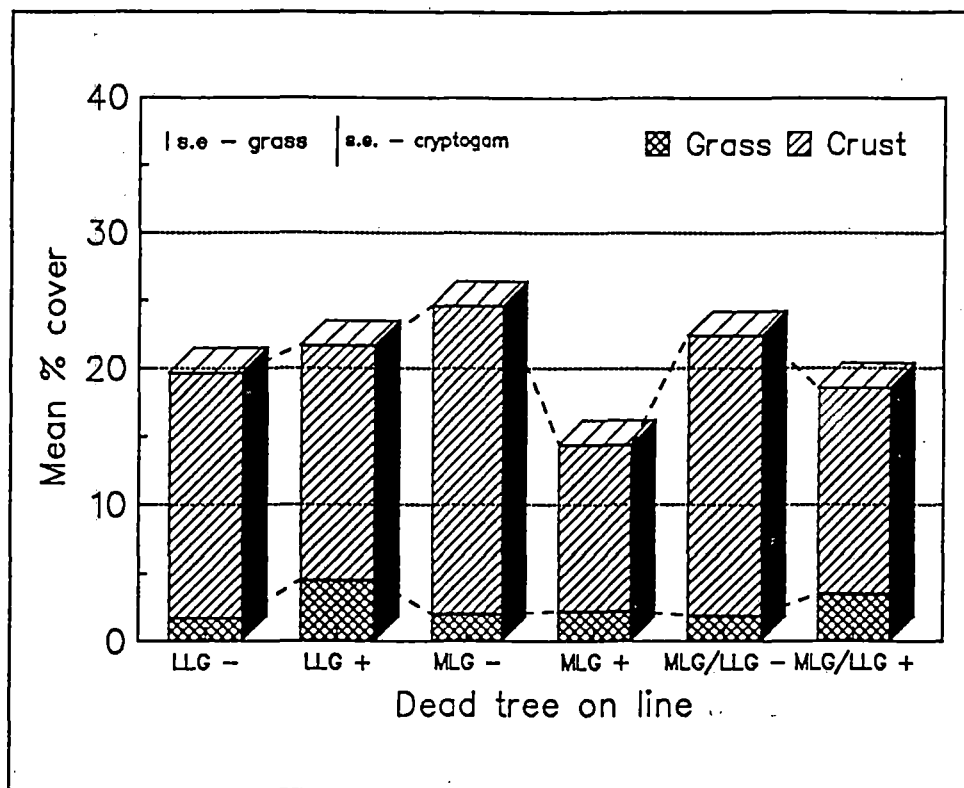


Figure 11. The mean percent cover of grass and total cryptogams for each class with and without a dead tree on the line (MLG; lines 8-11.99 m, LLG; lines >12 m).



Soil pH measurements at Comanche Canyon.

There were three cases when the bare ground differed in pH from that with a cryptogamic crust. In one case there was a significantly more negative difference ($P=0.01$) in the differential pH between bare ground and an adjacent patch of moss (Figure 12 c). It was hypothesized that if the pH immediately under the soil surface (Figure 12 a) was less than the pH at a depth of 9-12 cm (Figure 12 b) leaching would have occurred and therefore a more negative differential pH of cryptogam crusted soil compared to "bare soil" would indicate a greater degree of infiltration through the crust. Thus, this result indicated that a greater amount of leaching (infiltration) had occurred through the cover of moss. In another case where the crust was predominantly lichen (of predominately a species of *Cladonia* (CLA 2)), there was a mean positive pH differential for which one can invoke one of the following explanations (Figure 12 c). Either there was a surface accumulation of calcareous material so that the surface soil had a higher pH than the deeper soil or, possibly, there was acidifying microbial activity at the lower depth. Both scenarios would complicate any interpretations.

At one of the two BUC sites the pH differential of the bare ground was significantly ($P<0.01$) more negative than that of the soil with BUC (Figure 12 c). If this BUC was predominantly algae it agrees with other reports that infiltration maybe reduced through crusts high in algae. The reason for this phenomenon was first suggested by Fritsch (1922) who described the high degree of mucilaginous exudate from terricolous algae. However, in this situation, it does not follow that erosion would be greater under field conditions. The mucilaginous secretion would bind the soil particles together which could reduce wind erosion and water would likely follow the microchannels in the rough BUC encrusted surface seeping down through the gaps left by incomplete cryptogam cover.

Figure 12. (a) The pH of the soil at the surface (0-3 cm).

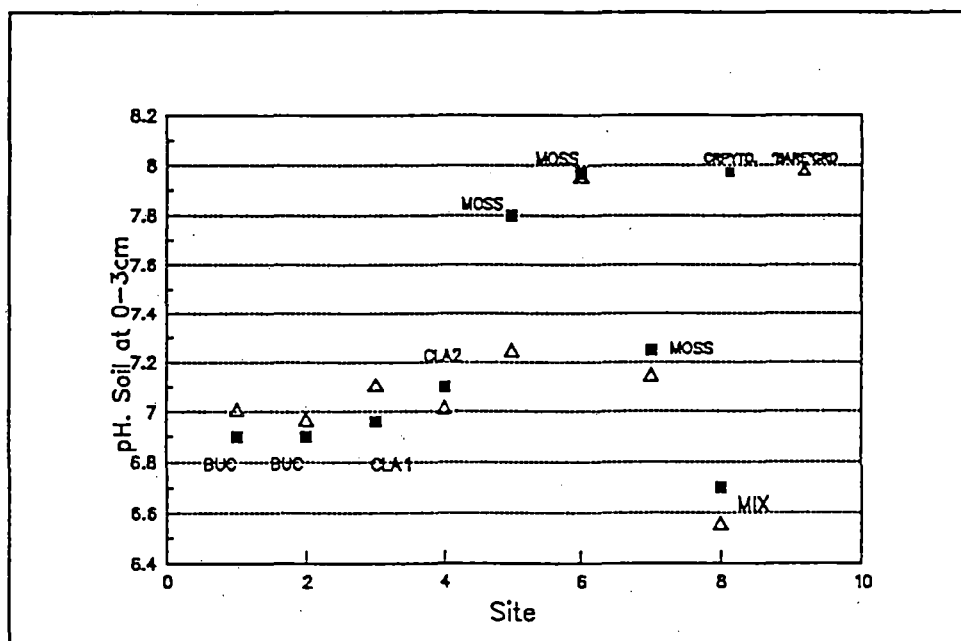


Figure 12. (b) The pH of the soil at a depth of 9-12 cm.

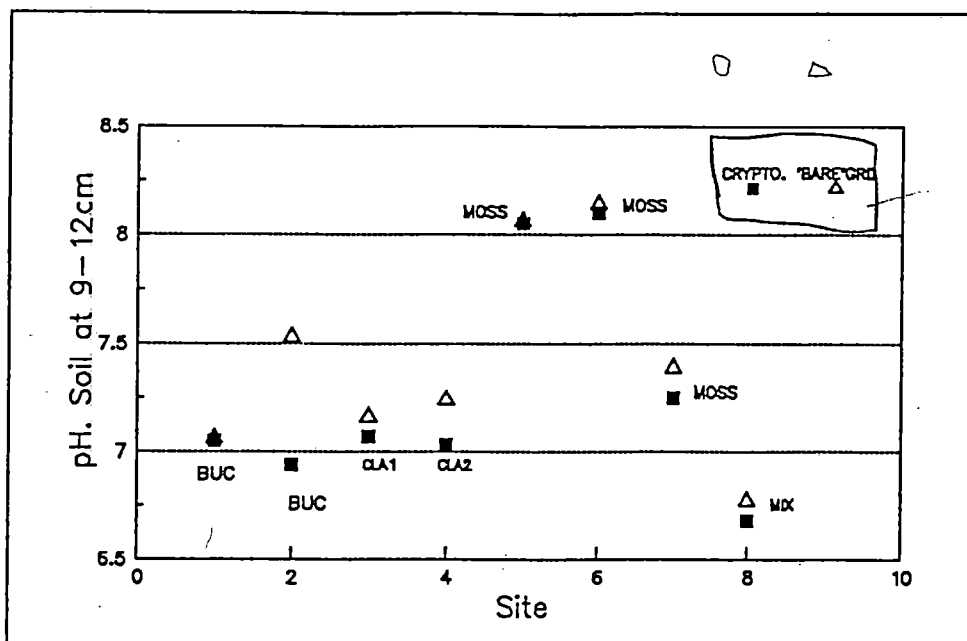
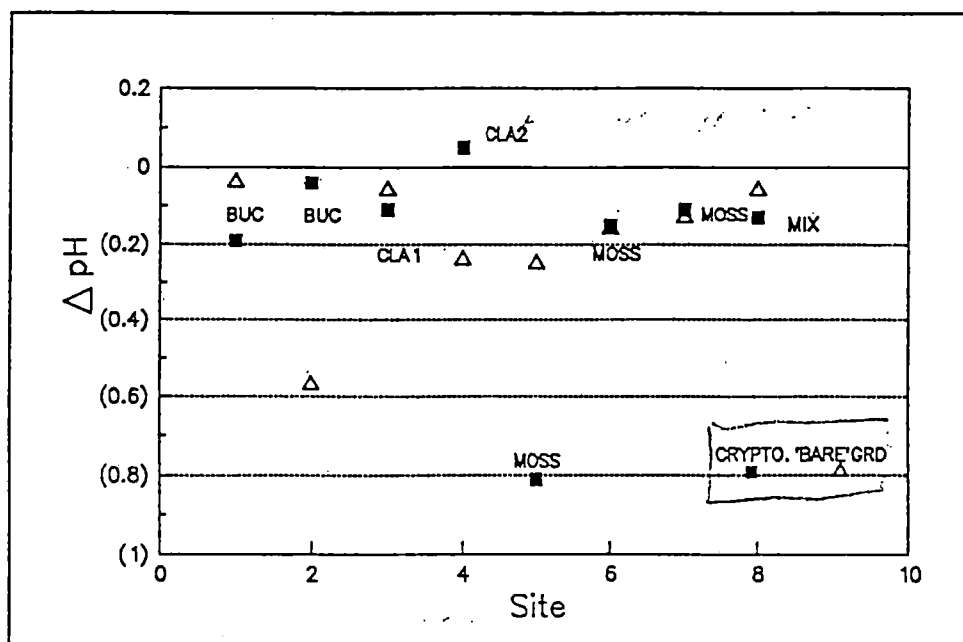


Figure 12 (c). The differential pH between the surface (0-3 cm) and deeper (9-12 cm) level.



Largo Mesa compared to Comanche Canyon.

Vascular plant cover.

Largo Mesa had a much higher ratio of juniper to pinon when compared to Comanche Canyon. Although, not tested statistically, visual observation was supported in our random choice of trees. Five junipers were chosen in the 16 lines surveyed at Largo Mesa, as compared to only 3 junipers in the total 48 lines at Comanche Canyon. In addition, at Largo Mesa, one central tree and one tree at the end of a transect were actually two trees growing intimately together, one a juniper and the other a pinon. Only one juniper was represented in the class of line length 8-11.99 m at Comanche Canyon. The proportion of needle debris on the transects that was under the tree canopy was the same on both mesas (Table 7). However, a greater proportion of the woody debris was under the canopy at Largo Mesa (Table 7).

One way analysis of variance for the cover on the transect line was analyzed by ANOVA and the results summarized in Table 8 and in Figure 13.

After arc sine transformation of the data the tree canopy cover was not significantly different from that at Comanche Canyon. Before data transformation, analysis indicated significance existed. As this is a preliminary study this fact should be born in mind. Heights of the trees at the transect ends were similar at both mesas; an average of 5.8 m at Largo Mesa and 5.9 m at Comanche Canyon. From observations made on the growth habit of the trees the greater canopy cover at Largo Mesa was ascribed to the wider tree spacing allowing greater branching of the trees. Between the two locations, the soil was equally pebbly but it was noted that the pebbles at Largo Mesa were, on average, smaller than 1 cm diameter as compared to those at Comanche Canyon which were, on average, larger than 1 cm.

Grasses were in significantly greater abundance at Largo Mesa (Table 8 and Figure 13). *Bouteloua* species (*B. gracilis* and *B. curtipendula*) were the most prominent. *Opuntia* species and seedling trees were absent on and around the transect lines at Largo Mesa, although some *Opuntia* were observed at other locations on the mesa. The species of vascular plants within 0.5 m each side of the line are described in Appendix 2. Those marked by an asterisk were unique to Largo Mesa as compared to Comanche Canyon. *Lupinus kingii* and *Lotus wrightii* were both abundant at Largo Mesa but absent at Comanche Canyon. There were no significant differences between the plots for vascular plant species at Largo Mesa.

Cryptogamic cover.

Foliose lichen was the morphological type that comprised 44.2% of the total lichen cover at Largo Mesa (Table 9). The major foliose lichen was *Xanthoparmelia chlorochroa* which was completely absent at the Comanche Canyon site. The black microphytic crust (BUC) that was so prevalent at Comanche Canyon comprised only a small portion of the total cryptogamic crust observed at Largo Mesa. However an algal component (in some instances recognizable as a *Nostoc* species in most others of unidentified species) of the crust was more in evidence at Largo Mesa. As these were ocular estimates of crust much of the algae, and all the diatoms and other microscopic components of the crust, at both sites were excluded from consideration in this preliminary study. It could have been that the algae, other than *Nostoc*, were more identifiable as such at Largo Mesa because of climatic conditions. There was significantly less cryptogamic crust on the line at Largo Mesa than Comanche Canyon (Figure 13 and Table 8). They were also other noticeable differences between the species present on each mesa. For example, *Cladonia chlorophaea* was in high abundance at Comanche Canyon but was not noticed at Largo Mesa whereas *Diploschistes scruposus* was very visible at Largo Mesa and there was very little at Comanche Canyon.

Lichens that favored a wood substrate for growth were found on woody debris at Largo Mesa. As at Comanche Canyon some were a species of *Usnea*. However another, unidentified foliose, type was equally abundant at Largo Mesa.

On average there were between 4 and 5 vascular plant species per line; 2 or 3 species of forb and one or two species of grass. There were no significant differences in the vascular plant distribution or the cover of the transects between the plots at Largo Mesa. This fact, along with the experimental design, allowed for the effect of compass bearing of the line on the cryptogamic crust to be analyzed. Aspect has been reported as having an important influence on cryptogamic crust development (Nash et al. 1977). This was examined by determining the amount of cryptogamic cover that was on the line in the 1 m that extended immediately past the canopy. There was a significant difference ($P = 0.0083$). Those lines north west of the tree had the highest amount, followed by the north east. The south east and south west pointing lines had, equally, the least abundance of cryptogams (Figure 14).

The effect of tree species on cryptogamic crust on the line in the 1 m that extended immediately past the canopy was also examined regardless of compass direction. In the 5 cases where a pinon and juniper were growing together the values were examined in a separate category. No significant differences could be determined (Data not shown).

The effect of a dead tree on the transects were analyzed for Largo Mesa and Comanche Canyon combined and individually. Comparing the two types of line (presence and absence of tree) using pooled data from the two sites and considering Largo Mesa lines alone there was, using a multifactor analysis, significantly less cryptogamic crust on the lines with the dead tree on them ($P = 0.017$). As at Comanche Canyon, there were no differences between grass cover on the lines (Figure 15). On a per line basis presence of woody debris is significantly, negatively correlated with lichen cover (correlation coefficient = -0.4 , $P = 0.02$) but the negative association with BUC was negligible and not statistically significant. This may also provide some explanation of why dead trees on the line had little effect on cryptogam cover on the longer length lines at Comanche Canyon. BUC, or perhaps other lichens, prevalent on long line lengths at Comanche Canyon may be able to tolerate woody debris.

As at Comanche Canyon there was a positive correlation between pebbles and lichen cover (correlation coefficient = 0.4 ; $P = 0.025$). When considering the MLG transects at both Comanche Canyon and Largo Mesa there was a positive correlation between cover of forbs and cover of BUC (correlation coefficient = 0.65 ; $P = 0.0001$) and cover of forbs and total cryptogam cover (correlation coefficient = 0.44 ; $p = 0.012$) but a negative correlation between total cryptogamic crust and grass (correlation coefficient = -0.3 ; $P = 0.07$). The component of the crust most negatively correlated with grass was BUC (correlation coefficient = -0.5 ; $P = 0.005$).

Table 7. Proportion of cryptogamic and debris cover on the line that was under the canopy.

Parameter measured	Mean		Probability ¹
	Largo mesa	Comanche Canyon	
% under canopy			
Lichen	18.13	7.41	ns
Moss	22.47	20.21	ns
BUC	3.05	2.92	ns
Needle debris	75.23	74.11	ns
Woody debris	69.84	52.42	*

¹ ns. Not significantly different $P > 0.05$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$

Figure 13. Description of mean cover on transect lines of 8-11.99 m long at Largo Mesa and Comanche Canyon.

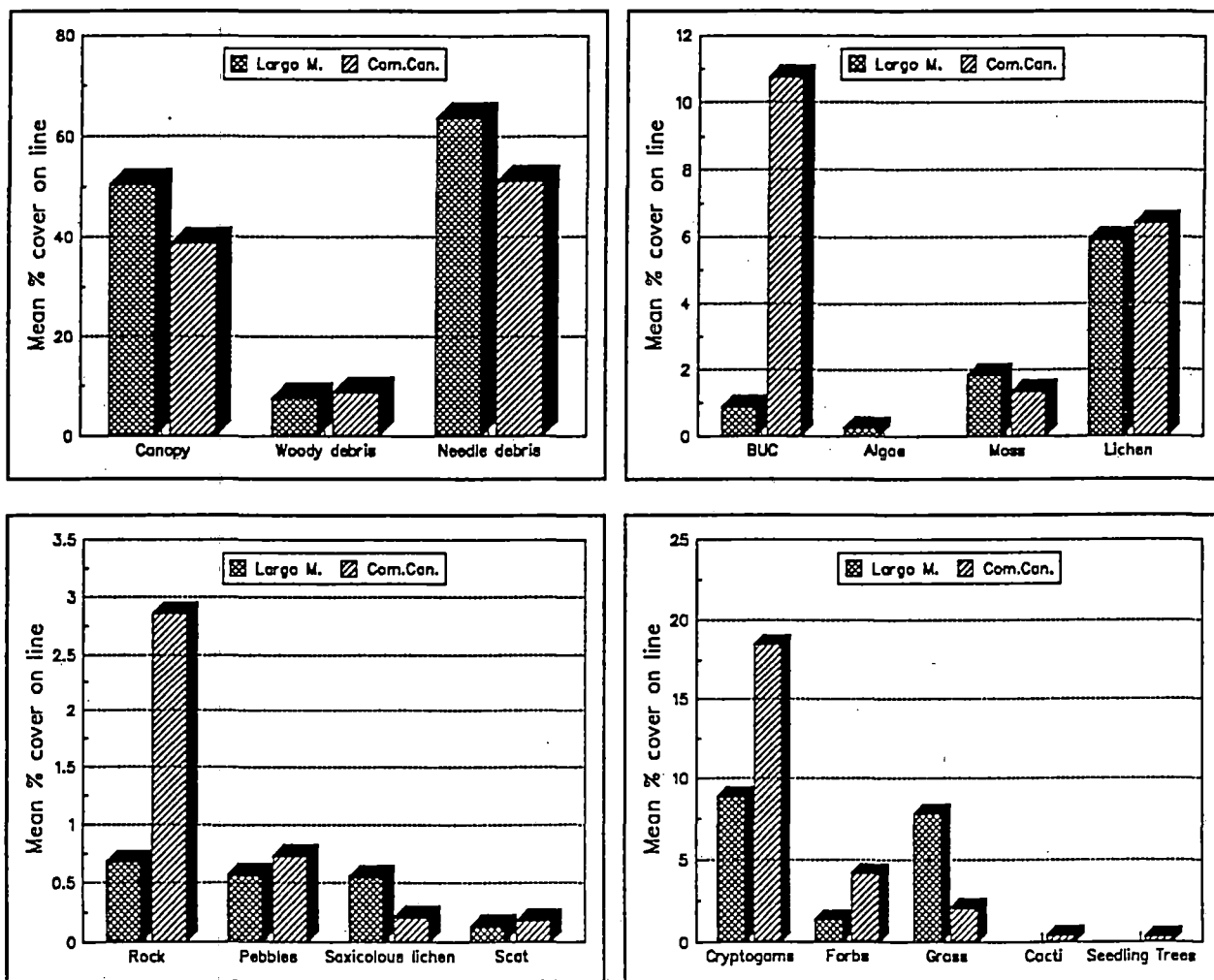


Table 8. A comparison between the percent cover on the lines (of lengths 8-11.99m only) at Largo Mesa and Comanche Canyon.

Parameter measured	Mean Largo mesa	Mean Comanche Canyon	Probability ¹
Length of line (cm)	975.9	987.9	ns
Soil class (no units)	2.25	2.13	ns
% of line:			
Total microphytic crust	8.87	18.5	**
BUC	0.87	10.75	***
Algae	0.24	0.00	**
Moss	1.83	1.35	ns
Lichen	5.93	6.41	ns
Saxicolous lichen	0.55	0.21	ns
Canopy	50.43	38.66	*
Woody debris	7.58	8.69	ns
Needle debris	63.6	51.22	ns
Forbs	1.34	4.19	*
Grass	7.81	2.07	***
Cacti	0.00	0.41	*
Yucca	0.00	0.12	ns
Seedling trees	0.00	0.31	ns
Shrubs	0.00	0.00	--
Scat	0.13	0.18	ns
Rock	0.68	2.86	ns
Pebbles	0.57	0.73	ns

¹ ns. Not significantly different $P > 0.05$;

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$

Table 9. The composition, by morphological type, of the terricolous lichen. (Lichen that was not readily distinguishable between the forms was included in the total lichen value (Table 7). This unidentified lichen was predominantly associated with BUC.)

Parameter measured	Mean Largo mesa	Mean Comanche Canyon	Probability ¹
% terrestrial lichen			
Foliose	44.15	13.32	**
Fruticose	46.36	54.05	ns
Crustose	5.56	9.73	ns
Unidentified	3.93	22.90	*

¹ ns. Not significantly different $P > 0.05$;

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$

Figure 14. The influence of compass direction on the number of cm of cryptogamic crust within 1 m outside the tree canopy.

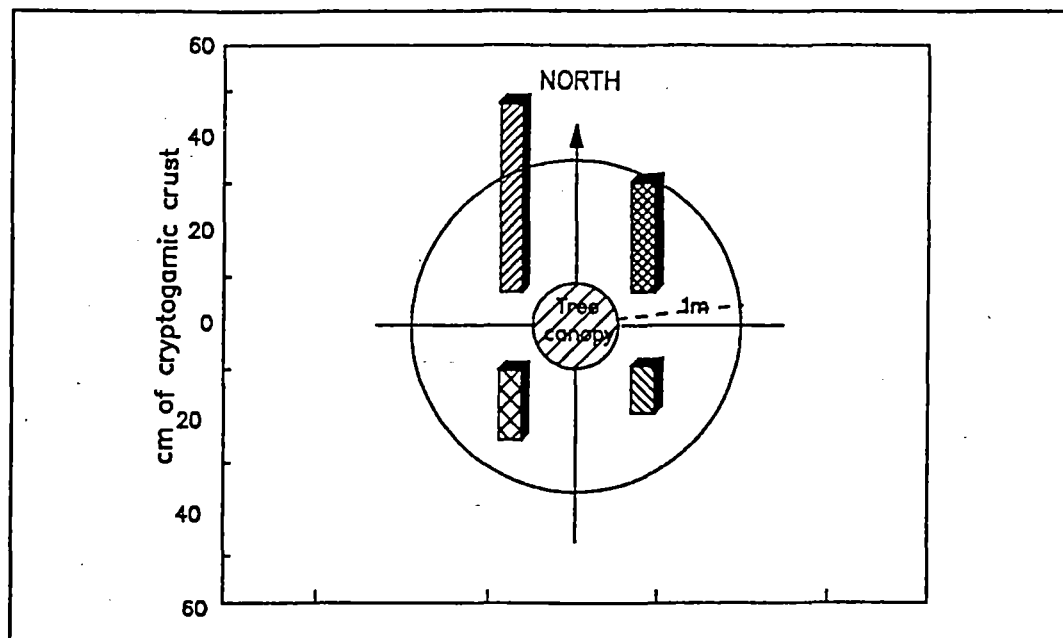
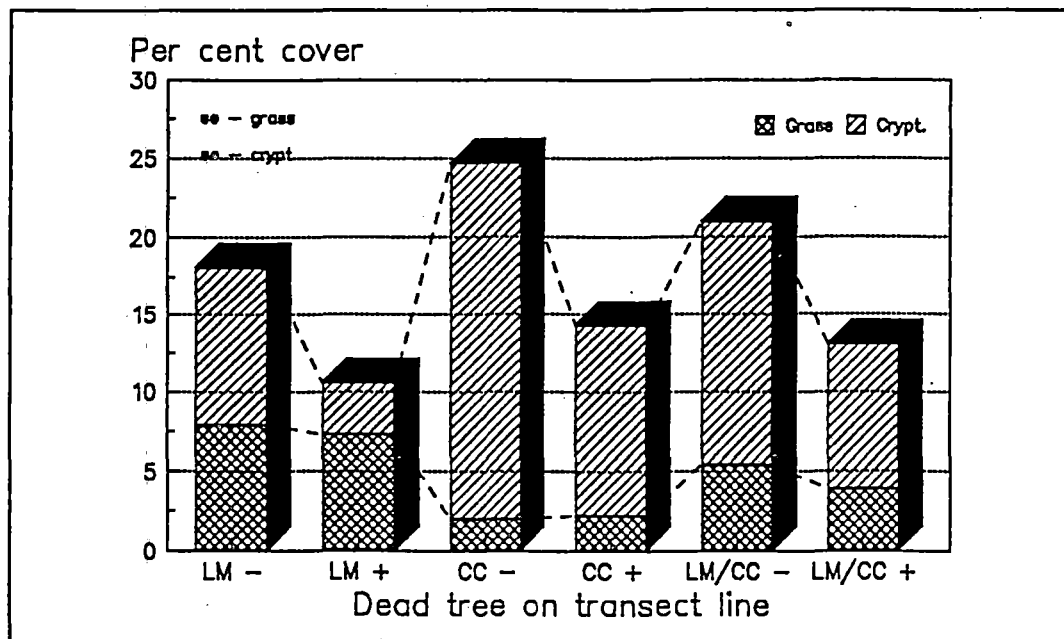


Figure 15. Graph demonstrating the difference in cryptogamic crust cover on a line with the absence (-) and presence (+) of a fallen tree at Largo Mesa (LM) and Comanche Canyon (CC).



Discussion and Conclusion.

The site at Largo Mesa and Comanche Canyon were significantly different for the species present, and for the percent transect cover, of both vascular plants and cryptogams. Although both were pinon-juniper stands the proportion of pinons to juniper were different. The marked difference between the two sites may make correlations between grass, forbs and terrestrial cryptogams misleading. In this particular study at Comanche Canyon, the environmental differences associated with line length along with the similarity between the class lengths for both vascular plant species and cryptogamic crust cover tends to preclude meaningful associations being made between specific vascular plant cover and the abundance of the different components of the cryptogamic crust. Class lengths were determined arbitrarily. A choice of a greater number of longer line lengths and the utilization of a sliding scale to compare cover may be useful for making such associations.

At both sites there was a negative association between percent line cover by the canopy and total cryptogamic crust. This supports the conclusion at Comanche Canyon that close tree spacing lowers crust abundance. However, at Comanche Canyon tree spacing greater than 4 m permitted a substantial cover. Woody debris and needle debris were both negatively associated with certain components of the cryptogamic crust. In addition, at both sites, pebbles were positively associated with cryptogam colonization of adjacent soil. A dead, decaying tree on transects 8-12 m long apparently reduced the cryptogamic cover. This could be due to allelopathic effect from the decaying wood and needle debris or because of residual affects of the tree canopy and the slow growth by cryptogams.

Aspect influenced abundance of cryptogamic crust at Largo Mesa. Within 1 m of the tree canopy the greatest amount of crust was observed in the north west quadrant. The reason for the distribution is not readily apparent as it is not the warmest nor coolest quadrant. Possibly prevailing wind direction or precipitation pattern on this Mesa accounts for the phenomenon.

When considering the MLG transects at both mesas there was a positive correlation between cover of forbs and cover of BUC and cover of forbs and total cryptogam cover but a negative correlation between total cryptogamic crust and grass. The component of the crust most negatively correlated with grass was BUC. It seems likely that certain species of cryptogams are influenced by certain species of grass, and vice versa (West 1990). It is not a simple relationship. For example, in a greenhouse study, negative correlation between grass seed germination and moss crust (litter) was observed but there was stimulation of seedling growth by the same cover 4 weeks after germination (Schlatterer and Tisdale, 1960). Competition for nutrients, water or allelopathic interactions can be hypothesized to account for the phenomenon but such inferences are beyond the scope of this study. Also, it was noteworthy that there was a higher degree of canopy cover over the lines at Largo Mesa which supported the result of a negative correlation between canopy cover and cryptogamic crust at Comanche Canyon. However, due to the differences between sites with respect to vascular plants as well as terrestrial cryptogam species these correlations must be treated cautiously. For example, *Cladonia chlorophaea* and *Ipomopsis multiflora* were in high abundance at Comanche Canyon but were not noticed at Largo Mesa whereas *Xanthoparmelia chlorochroa* and *Lupinus kingii* were very visible at Largo Mesa but they were absent at Comanche Canyon. Also, edaphic and environmental differences at each site must be considered.

Results from this preliminary study on cryptogamic crust and its influence on soil pH as a measure of infiltration suggested that presence or absence of the crust may influence the differential pH of the soil. In addition the differences in differential pH between crust and bare ground were related to the composition of the crust. Therefore, this method could lead to insights on the how the different types of crusts influence erosion processes.

The abundance of microphytic (cryptogamic) soil crust is believed to be an important indicator of the extent to which an area has been disturbed and may provide insight on the progress in the recovery of a logged, grazed or otherwise disturbed community. Absence of a microphytic or cryptogamic soil crust is generally understood to lead to an increase in soil erosion (West, 1990). As ocular estimates tend to be open to operator variation and probably underestimate the biomass of crust present developing a simple procedure based on the measurement of chlorophyll on the soil surface (Beymer and Klopatek, 1992) may be,

ultimately, an accurate and rapid method to determine the state of the soil surface for purposes of monitoring land deterioration and/or soil erosion.

The measure of percent cover on a transect was successful in providing estimates of the amount of cover as influenced by tree spacing, canopy cover, and debris. However, the frequency data was very valuable in determining the distribution of higher plant species. As this study has shown that, generally, cryptogamic crusts are considerably reduced on thick needle debris further studies that investigate transects that exclude the canopy from calculation but are expanded to widths of one m between trees should be considered so that a greater area is considered for both cryptogams as well as vascular plants. For example, this approach could allow spatial analysis of the association between cryptogams and grass tussocks. A survey on areas that had been recently harvested for fuel wood would be a useful comparison to these two undisturbed areas. Further studies on a greater number of locations along with examination of tree spacing within the individual locations should be undertaken so that generalizations can be made from the conclusions reached in this study can be made. Namely: Short distances (<4 m) between trees prevent the development of crusts rich in lichens. In some instances areas with abundant grass cover have low cover of cryptogams. High forb cover is positively associated with cryptogamic crust. The extent to which debris covers a line is inversely correlated with the amount of cryptogamic crust on the line but pebbles are positively correlated to high lichen cover. In some circumstances lines opened up by the falling of a tree have a significantly lower cover of cryptogams without a different degree grass cover than lines without the prior influence of a trees canopy.

Acknowledgements.

Field assistance was conscientiously given for this survey by Scott Davis and Philip Tonne.

Appendix 2

Vascular plant species in vicinity of transects at Largo Mesa

Bahia dissecta
Eriogonum jamesii
Eriogonum alatum
Cheopodium fremontii
*Thelypodium wrightii**
*Descurainia sp.**
Gutierrezia sarothrae
Erysimum capitatum
*Astragalus sp.**
*Lotus wrightii**
*Lupinus kingii**
Mirabilis grandiflora
*Mirabilis oxybaphoides**
Lesquerella sp

*Oryzopsis micrantha**
Bouteloua gracilis
Aristida sp.
Bouteloua curtipendula
Koeleria cristata
Sitanton hystrix
*Blepharoneuron tricholepis**

* Species marked with an asterisk were not observed at Comanche Canyon.

Appendix 3

Vascular plant species in vicinity of transects at Comanche Canyon

Bahia dissecta
Hymenoxys acaulis
Eriogonum jamesii
Lepidium montanum
Haplopappus gracilis
Eriogonum alatum
Hymenoxys richardsonii
*Ipomopsis multiflora**
Gutierrezia sarothrae
Erysimum capitatum
Hymenopappus newberryi.
Anntenaria marginata
*Hedeoma drummondii**
Euphorbia sp.
Lesquerella rectipes
*Lithospermum incisum**
*Pentemon linarioides**
Chrysopsis sp.
Erigeron flagellaris
Erigeron (divergens)
*Yucca baccata**
*Opuntia fragilis**
Opuntia sp.
*Echinocereus viridiflorus**

Hilaria jamesii
Bouteloua gracilis
Aristida sp.
Bouteloua curtipendula
Koeleria cristata
Sitanion hystrix

* Species marked with an asterisk were not observed at Largo Mesa.